A possible mechanism for producing the threshold enhancement in $J/\psi \to \gamma p\bar{p}$

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(Dated: August 18, 2009)

In the J/ψ radiative decay channels $J/\psi \to \gamma V\bar{V}$, the result of partial wave analysis indicates that the $V\bar{V}$ systems are predominately pseudoscalar component, and most of these channels have relatively large branching ratios at an order of 10^{-3}. Meanwhile, vector mesons, such as ρ, ω and K^*, have strong couplings with nucleons and/or hyperons. This suggests a dynamical mechanism describing the $\eta p\bar{p}$ form factors for higher η mesons, such as $\eta(1405/1475)$ and $\eta(1760)$. It is thus natural to expect that rescatterings of these vector meson pairs into $p\bar{p}$ of 0^- partial wave could be an important source contributing to $J/\psi \to \gamma p\bar{p}$ of which the branching ratio is at the order of 10^{-4}. Our calculation justifies this point. In particular, we find that interferences between different rescattering amplitudes can produce a significant threshold enhancement in the invariant mass spectrum of $p\bar{p}$. Without introducing dramatic ingredients, our model provides a natural explanation for the peculiar threshold enhancement observed by BES-II in $J/\psi \to \gamma p\bar{p}$. Additional experimental constraints on the $V\bar{V} \to p\bar{p}$ transitions are examined. This mechanism in $J/\psi \to \omega p\bar{p}$ is also discussed.

PACS numbers: 13.20.Gd, 13.38.-b, 13.30.Eg

I. INTRODUCTION

BES-II Collaboration has reported a narrow threshold enhancement near $2m_p$ in the invariant mass spectrum of $p\bar{p}$ pairs from $J/\psi \to \gamma p\bar{p}$ decays [1]. The result of partial wave analysis (PWA) shows that if it is interpreted as a 0^{-+} resonance, its mass is about $M = 1859^{+3}_{-10}(\text{stat})^{+5}_{-25}(\text{syst})$ MeV, and its decay width is about $\Gamma < 30$ MeV at 90% C.L. This observed enhancement has stimulated many theoretical studies of its underlying structure. Some interpret it as a glueball candidate [2, 3, 4] or a baryonium [5, 6, 7, 8], and some others take into account the effect of the final state $p\bar{p}$ interactions [9, 10, 11, 12, 13, 14, 15]. There will be some peculiar characters if it is interpreted as a glueball. For instance, it can couple to a pair of vector mesons $V\bar{V}$, and the decay channel will be flavor independent, but we have not yet found such a narrow state in $J/\psi \to \gamma V\bar{V}$ decays considering there has been a sizeable accumulation of events.

On the other hand, there exists an interesting phenomenon that may be related to the $J/\psi \to \gamma p\bar{p}$ decay. We notice that in the process of J/ψ radiative decays $J/\psi \to \gamma V\bar{V}$, where $V\bar{V}$ represent $\rho\rho$, $\omega\omega$ or $K^*\bar{K}^*$ and so on, the $V\bar{V}$ invariant mass distribution is dominated by the 0^- components in all of these channels [16, 17, 18, 19, 20]. Nevertheless, these vector mesons generally have strong couplings with the nucleons and/or hyperons. As a result, we expect that the $V\bar{V}$ rescattering into $p\bar{p}$ could play an important role in the description of the pseudoscalar-$p\bar{p}$ coupling form factor in $J/\psi \to \gamma p\bar{p}$. This is also consistent with that the $p\bar{p}$ system has an important 0^- component. We list in Tab. I some relatively significant channels of which the branching ratios are at the order of 10^{-3} and which might contribute to the rescattering. It is worth noting that the experimental values of $BR(J/\psi \to \gamma\eta(1405/1475)) \times BR(\eta(1405/1475) \to \rho\rho)$ and $BR(J/\psi \to \gamma\eta(1760)) \times BR(\eta(1760) \to \rho\rho)$ are extracted from $J/\psi \to 4\pi\gamma$, where the results greatly depend on the fitting methods [20]. A similar problem is also with the data for $BR(J/\psi \to \gamma 0^-) \times BR(0^- \to K^*\bar{K}^*)$ [18]. In this sense, the branching ratios displayed in Table I still have large uncertainties at the order of 10^{-3}. However, we shall show later that the sizeable $V\bar{V}$ rescatterings into $p\bar{p}$ cannot be neglected at all if the uncertainties were not more than one order of magnitude. For the purpose of exploring possibilities of reproducing the line shape of the threshold enhancement in $J/\psi \to \gamma p\bar{p}$ [1], we can adopt such a set of values to determine the coupling constants and examine the model-dependent and independent aspects in this decay transition.

BES-II also reported another similar resonance observed in the $\pi^+\pi^-\eta'$ invariant mass spectrum in $J/\psi \to \gamma\pi^+\pi^-\eta'$, which has a mass $M = 1833.7 \pm 6.1(\text{stat}) \pm 2.7(\text{syst})$ MeV and a width $\Gamma = 67.7 \pm 20.3(\text{stat}) \pm 7.7(\text{syst})$ MeV after a fit with a Breit-Wigner function [21]. If these two experimental results can be attributed to the same resonance, it would be an additional evidence for the resonant property of this enhancement. But we should note that the present experimental data do not allow one to conclude whether $X(1835) \to \pi^+\pi^-\eta'$ is via quasi-two-body decay (e.g. through $X(1835) \to \sigma\eta' \to \pi^+\pi^-\eta'$) or three-body decay. In order to understand the nature of the threshold enhancement in $J/\psi \to \gamma p\bar{p}$, one should explore various possibilities in the transition mechanism. This forms our motivation in this work to study the role played by vector meson $V\bar{V}$ rescatterings in $J/\psi \to \gamma p\bar{p}$.

Channel	BR ($\times 10^{-3}$)	Ref.
$\gamma\eta(1405/1475) \to \gamma\rho\rho$	1.83 ± 0.39	[20]
$\gamma\eta(1760) \to \gamma\rho\rho$	1.44 ± 0.33	[20]
$\gamma\eta(1760) \to \gamma\omega\omega$	1.98 ± 0.33	[17]
$\gamma 0^- \to \gamma K^* \bar{K}^*$	2.3 ± 0.9	[18]

TABLE I: Branching ratios of $J/\psi \to \gamma\eta \to \gamma V\bar{V}$, where 0^- represents a broad 0^- resonance with the mass $M = 1800 \pm 100$ MeV and the decay width $\Gamma = 500 \pm 200$ MeV [18].

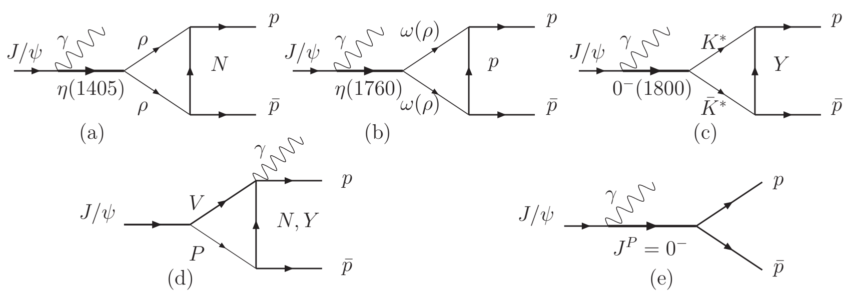

FIG. 1: Feynman diagrams for $J/\psi \to \gamma p\bar{p}$. Diagrams (a)-(c) are via $V\bar{V}$ rescattering, where N and Y represent the exchanged nucleon or hyperon, respectively. Diagram (d) is VP rescattering, where V and P represent vector and pseudoscalar meson, respectively, such as $\rho\pi$, $K^*\bar{K}$ and so on. Diagram (e) is $p\bar{p}$ production via direct couplings to pseudoscalar resonances.

As follows, we first provide details of our theoretical model in Sect. II. Numerical results and discussions will be given in Sect. III. A brief summary will be given in Sect. IV.

II. THE MODEL

The Feynman diagrams that illustrate the rescattering transitions are shown in Fig. 1. Considering that the coupling constants of $K^*N\Sigma$ are smaller than those of $K^*N\Lambda$, especially the tensor coupling constant κ [22], we do not include the contribution from exchanging Σ baryon in Fig. 1(c). There are also other rescattering processes that can contribute to the decay channel $J/\psi \to \gamma p\bar{p}$ as illustrated in Fig. 1(d). But note that the strong decay $J/\psi \to VP$ will exchange three gluons as a minimum number, while the production of η resonances in Fig. 1(a)-(c) can occur via exchanging two gluons. The transition of Fig. 1(d) will be relatively suppressed. Thus, we do not include their contribution at this moment.

We distinguish contributions from light pseudoscalar meson such as $\eta(547)$. Such states have relatively small couplings to $J/\psi\gamma$ which can be determined by the J/ψ radiative decays. Also, we have better knowledge on their couplings to nucleons. Since their masses are far below the $p\bar{p}$ threshold, their contributions to $J/\psi \to \gamma p\bar{p}$ are strongly suppressed. We call such contributions as direct couplings and they are presented by Fig. 1(e).

In the isoscalar channel for $p\bar{p}$, the large branching ratios of $J/\psi \to \gamma\eta \to \gamma V\bar{V}$ and sizeable VNN couplings actually allow us to study the form factors for intermediate massive η mesons to $p\bar{p}$ by $V\bar{V}$ rescatterings. Qualitatively, the $p\bar{p}$ invariant mass spectrum could be sensitive to the dynamical details of the $\eta p\bar{p}$ form factors. This is different from treating the $\eta p\bar{p}$ by a single coupling parameter. Our purpose is to explicitly calculate the $\eta p\bar{p}$ form factors via intermediate $V\bar{V}$ rescatterings based on available experimental data [16, 17, 18, 19, 20].

The following effective Lagrangians are applied for the evaluation of those Feynman diagrams:

$$\mathcal{L}_{\rho NN} = g_{\rho NN}\bar{N}\left(\gamma^\mu \vec{\tau}\cdot\vec{\rho}_\mu + \frac{\kappa_\rho}{2m_N}\sigma^{\mu\nu}\vec{\tau}\cdot\partial_\mu\vec{\rho}_\nu\right)N, \quad (1)$$

$$\mathcal{L}_{\omega NN} = g_{\omega NN}\bar{N}\left(\gamma^\mu\omega_\mu + \frac{\kappa_\omega}{2m_N}\sigma^{\mu\nu}\partial_\mu\omega_\nu\right)N, \quad (2)$$

$$\mathcal{L}_{K^*N\Lambda} = g_{K^*N\Lambda}\bar{N}\left(\gamma^\mu\Lambda K^*_\mu + \frac{\kappa_{K^*}}{2m_N}\sigma^{\mu\nu}\Lambda\partial_\mu K^*_\nu\right) + H.c., \quad (3)$$

	ρNN	ωNN	$K^* N\Lambda$	$K^* N\Sigma$
g_{VBB}	2.97	10.36	-4.26	-2.46
κ	4.22	0.41	2.66	-0.47

TABLE II: Coupling constants of VBB taken from Ref. [22].

$$
\begin{aligned}
\mathcal{L}_{\gamma\psi\eta} &= e\frac{g_{\gamma\psi\eta}}{m_\psi}\epsilon_{\alpha\beta\gamma\delta}\partial^\alpha A^\beta \partial^\gamma \psi^\delta \eta, &(4)\\
\mathcal{L}_{VV\eta} &= \frac{g_{VV\eta}}{m_V}\epsilon_{\alpha\beta\gamma\delta}\partial^\alpha V^\beta \partial^\gamma \bar{V}^\delta \eta, &(5)\\
\mathcal{L}_{\eta NN} &= -ig_{\eta NN}\bar{N}\gamma_5 \eta N, &(6)\\
\mathcal{L}_{\omega\psi\eta} &= \frac{g_{\omega\psi\eta}}{m_\psi}\epsilon_{\alpha\beta\gamma\delta}\partial^\alpha \psi^\beta \partial^\gamma \omega^\delta \eta, &(7)
\end{aligned}
$$

where $\vec{\tau}$ are Pauli matrices, $\vec{\rho}$ denotes isospin triplet, N and K^* denote isospin doublets which are defined as follows:

$$
N = \begin{pmatrix} p \\ n \end{pmatrix}, \quad K^* = \begin{pmatrix} K^{*+} \\ K^{*0} \end{pmatrix}, \tag{8}
$$

and η and V denote the pseudoscalar and vector fields, respectively. In our framework, η represents $\eta(1405/1475)$, $\eta(1760)$ [23] and a broad 0^- resonance $X(1800)$ [18], respectively.

The momenta of the intermediate meson rescatterings in Fig. 1(a)-(c) are denoted as $J/\psi(P) \to \gamma(k)\eta(k_1) \to \gamma V(q_1)\bar{V}(q_2) \to \gamma p(p_1)\bar{p}(p_2)$. Then the amplitude is given by

$$
\begin{aligned}
\mathcal{M}_\eta &= e\frac{g_{\gamma\psi\eta}}{m_\psi}\frac{\epsilon_{\alpha\beta\gamma\delta}k^\alpha \epsilon^{*\beta} P^\gamma \epsilon^\delta_\psi}{s - m_\eta^2 + im_\eta\Gamma_\eta}\int \frac{d^4 q}{(2\pi)^4}\\
&\times \frac{A(\eta \to VV \to p\bar{p})}{(q_1^2 - m_V^2)(q_2^2 - m_V^2)}\mathcal{F}(q^2),
\end{aligned} \tag{9}
$$

where

$$
\begin{aligned}
& A(\eta \to VV \to p\bar{p})\\
\equiv\ & \frac{g_{VV\eta}}{m_V}\epsilon_{\alpha\beta\gamma\delta}q_1^\alpha q_2^\gamma \times g_{VBB}^2 \bar{u}(p_1)\left(\gamma^\beta + \frac{i\kappa}{2m_N}\sigma^{\beta\mu}q_{1\mu}\right)\\
& \times \frac{\not{q} + m_B}{q^2 - m_B^2}\left(\gamma^\delta + \frac{i\kappa}{2m_N}\sigma^{\delta\nu}q_{2\nu}\right)v(p_2).
\end{aligned} \tag{10}
$$

Since the exchanged baryon is off-shell, we introduce a dipole form factor [24] as follows to eliminate the divergence of the loop-momentum integral:

$$
\mathcal{F}(q^2) = \left(\frac{\Lambda^2 - m_B^2}{\Lambda^2 - q^2}\right)^n, \tag{11}
$$

with $n = 2$. We note that a monopole form factor, i.e. $n = 1$, will be unable to kill the divergence. In principle, the experimental data for $p\bar{p}$ annihilation into VV can provide some constraints on the form factors and couplings. We will discuss this later in details. To evaluate the loop amplitude, we apply the software package LoopTools [25].

The VBB couplings are taken from the Nijmegen potential model [22], and listed in Table II. Although the values may be different among different models, they are all within a commonly accepted range in the literature. We define

$$
g_A \equiv e\frac{g_{\gamma\psi\eta}}{m_\psi}\frac{g_{VV\eta}}{m_V}, \tag{12}
$$

thus, the couplings g_A can be determined by the branching ratios $BR(J/\psi \to \gamma\eta) \times BR(\eta \to V\bar{V})$ listed in Table I. The numerical values are displayed in Table III.

An interesting feature arising from the $\rho\rho$ and $\omega\omega$ rescatterings is that all of them contribute to $p\bar{p}$ significantly. Note that these three amplitudes have absorptive part which can be determined in the on-shell approximation. We find that they individually overestimate the branching ratios for $J/\psi \to \gamma p\bar{p}$, and turn out to be much larger than the

	$\eta(1405/1475)\rho\rho$	$\eta(1760)\omega\omega$	$\eta(1760)\rho\rho$	$(0^-)K^*\bar{K}^*$
g_A (GeV^{-2})	0.024	0.015	0.007	0.038

TABLE III: Couplings of $J/\psi \to \gamma\eta \to \gamma V\bar{V}$ for different intermediate pseudoscalar mesons.

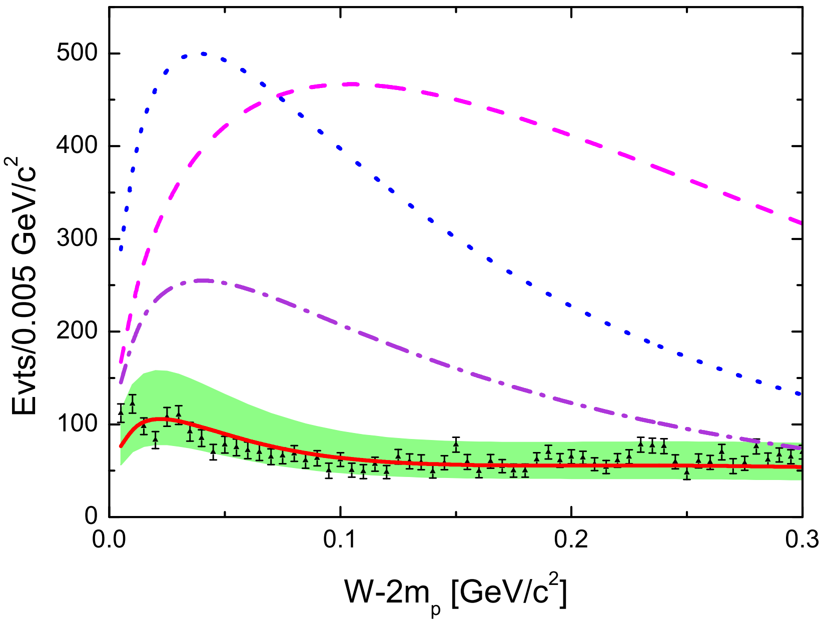

FIG. 2: The $p\bar{p}$ invariant mass spectrum of $J/\psi \to \gamma p\bar{p}$. The dashed, dotted, and dot-dashed lines correspond to contributions from $\rho\rho_{\eta(1405)}$, $\omega\omega_{\eta(1760)}$, and $\rho\rho_{\eta(1760)}$-rescattering, respectively. The solid line is the overall interference with $\Lambda \simeq 1.17$ GeV and $\theta \simeq \pi$, $\phi \simeq -\pi/2$. The lower and upper bound of the shadowed area correspond to $\Lambda = 1.15$ and 1.20 GeV, respectively. The triangle with error bar represents the experimental data from Ref. [1].

direct transitions. This phenomenon suggests that rescattering amplitudes of the intermediate $\eta(1405/1475) \to \rho\rho$, $\eta(1760) \to \omega\omega$ and a relatively smaller one $\eta(1760) \to \rho\rho$ should have a destructive interference to suppress the overall amplitude in order to be consistent with the experimental magnitude [1]. Because of this constraint, we introduce two relative phases $e^{i\theta}$ and $e^{i\phi}$ between these amplitudes, i.e.

$$\mathcal{M} = \mathcal{M}_{\eta}^{dir} + \mathcal{M}_{\eta(1405)}^{\rho\rho,res} + e^{i\theta}\mathcal{M}_{\eta(1760)}^{\omega\omega,res} + e^{i\phi}\mathcal{M}_{\eta(1760)}^{\rho\rho,res}, \tag{13}$$

where $\mathcal{M}^{dir}$ and $\mathcal{M}^{res}$ denote the direct and rescattering amplitudes, respectively. We note that the mesons in the loops are generally treated as fundamental fields with infinitely narrow widths in the effective Lagrangian approach. The relative phase angles are thus introduced to take into account the size effects arising from the meson propagators and interaction vertices as commonly adopted. Since the contributions from the direct transitions are negligibly small, the relative phases are not sensitive to them and we do not discuss them in the following parts. In comparison with the data [1] we find that the relative phases $\theta \simeq \pi$ and $\phi \simeq -\pi/2$ leading to destructive interferences are favored.

III. NUMERICAL RESULTS AND DISCUSSIONS

A. Results for $J/\psi \to \gamma p\bar{p}$

In Fig. 2, we plot the invariant mass spectrum of the $p\bar{p}$ for the rescattering transitions, i.e. $\eta(1405/1475) \to \rho\rho$, $\eta(1760) \to \omega\omega$ and $\eta(1760) \to \rho\rho$, respectively. The coherent results are shown by the solid curve, with $\Lambda \simeq 1.17$ GeV, and a bound given by $\Lambda = 1.15 \sim 1.20$ GeV. It shows that the contributions from the $\eta(1405/1475) \to \rho\rho$, $\eta(1760) \to \omega\omega$ and $\eta(1760) \to \rho\rho$ rescatterings are much larger than their coherent sum. Nevertheless, at large value of $(W - 2m_p)$,

these contributions have different behaviors. It is interesting to see the consequence of the interferences among these amplitudes which produces the enhancement at low $(W-2m_p)$ and flattened cross sections at large $(W-2m_p)$.

There are essential points which should be clarified here:

I) The $V\bar{V}$ rescattering mechanism can be recognized as a dynamical account of the energy-dependent $\eta p\bar{p}$ form factors.

II) We emphasize again that such a prescription is based on the experimental evidence for the dominant 0^{-+} partial wave for $V\bar{V}$ in $J/\psi \to \gamma V\bar{V}$, and significantly large VNN couplings. Therefore, we can expect to gain much better insights into $J/\psi \to \gamma p\bar{p}$ reaction mechanism, in particular, for the 0^{-+} partial wave in the $p\bar{p}$ spectrum.

III) The large cross sections given by intermediate $V\bar{V}$ rescatterings imply that there must exist destructive phases among those amplitudes for which phase angles θ and ϕ are introduced for the dominant transition amplitudes. This feature can be regarded as less model-dependent since large contributions from the $V\bar{V}$ rescatterings seem to be inevitable. We shall investigate this in $p\bar{p}$ annihilation later to show that the $V\bar{V}$ rescatterings have not been overestimated. In contrast, we note that the behavior of the cancellations would be model-dependent. The phase angles are determined in such a way that the cancellations is required to produce the threshold enhancement in the $p\bar{p}$ spectrum. However, for the purpose of exploring possibilities of producing the threshold enhancement in $p\bar{p}$ spectrum, such a requirement can be justified.

IV) We note that the data in Ref. [1] do not contain sufficient background estimate as emphasized by BES [26]. In particular, the data contain contaminations from $\pi^0 p\bar{p}$, and the detector efficiency (DE) has not been corrected. This will affect the determination of Λ which requires a better understanding of those pieces of information. As shown by the dotted curve in Fig. 3(a) of Ref. [1], the DE exhibits an overall flattened shape though it is slightly better at small $p\bar{p}$ invariant masses. Because of this, a shadowed area corresponding to $\Lambda = 1.15 \sim 1.20$ GeV is shown in Fig. 2. We can also see that the DE correction and background subtraction will not change the shape of the enhancement drastically.

B. Results for $p\bar{p} \to V\bar{V}$

As follows, we come to the key issue to investigate the $p\bar{p} \to V\bar{V}$ as an independent check of the $V\bar{V}$ rescattering mechanism. There are experimental data for $p\bar{p}$ annihilations into vector meson pairs [27, 28, 29, 30, 31]. By adopting the same couplings used in $J/\psi \to \gamma p\bar{p}$ via $V\bar{V}$ rescatterings, we can calculate the cross sections for $p\bar{p} \to V\bar{V}$ and then check whether the $V\bar{V}$-rescattering contributions have been overestimated or not.

The branching ratios for the $\omega\omega$ and $\rho^0\rho^0$ final state in $p\bar{p}$ annihilations at rest were measured, $BR(p\bar{p} \to \omega\omega) = (3.32 \pm 0.34) \times 10^{-2}$ [27] and $BR(p\bar{p} \to \rho^0\rho^0) = (0.4 \pm 0.3) \times 10^{-2}$ [28]. However, the total cross sections with p and $\bar{p}$ at rest are not available. We then adopt the total cross section, $\sigma_T = 250$ mb with $p_{Lab} = 200$ MeV/c for the incoming antiproton beam to estimate the $\omega\omega$ and $\rho^0\rho^0$ production cross sections. It gives

$$\begin{aligned}\sigma_{exp}(p\bar{p} \to \omega\omega) &\approx 8.3 \pm 0.85 \text{ mb},\\ \sigma_{exp}(p\bar{p} \to \rho^0\rho^0) &\approx 1 \pm 0.75 \text{ mb}.\end{aligned}$$

For $p\bar{p}$ with low relative momenta, the cross sections should be dominated by the relative S wave, i.e. the orbital angular momentum between p and $\bar{p}$ is zero. Furthermore, the configuration of ${}^{2S+1}L_J = {}^3S_1$ will have $C = -1$. Thus, it will be suppressed due to C-parity violation when it couples to $\omega\omega$ and $\rho^0\rho^0$. The S-wave decay will then occur via the ${}^1S_0$ configuration, and the cross section can be estimated by using the following projector for the $p\bar{p}$ system [32]:

$$\begin{aligned}\Pi_0(p_1, p_2) &= -\sum_{\lambda_1,\lambda_2} u(p_1,\lambda_1)\bar{v}(p_2,\lambda_2)\langle\frac{1}{2}\lambda_1\frac{1}{2}\lambda_2|00\rangle\\ &= \frac{1}{2\sqrt{2}(E+m_N)}(\not{p}_1 + m_N)(1+\gamma^0)\gamma_5(\not{p}_2 - m_N),\end{aligned} \tag{14}$$

where $E = \sqrt{(p_1+p_2)^2}/2$.

With the same effective Lagrangians, form factors and coupling constants as in $J/\psi \to \gamma p\bar{p}$, and with the cut-off energy $\Lambda = 1.15 \sim 1.20$ GeV, we obtain the following cross sections:

$$\begin{aligned}\sigma_{th}(p\bar{p} \to \omega\omega) &\approx 2.4 \sim 4.7 \text{ mb},\\ \sigma_{th}(p\bar{p} \to \rho^0\rho^0) &\approx 2.0 \sim 3.9 \text{ mb},\end{aligned}$$

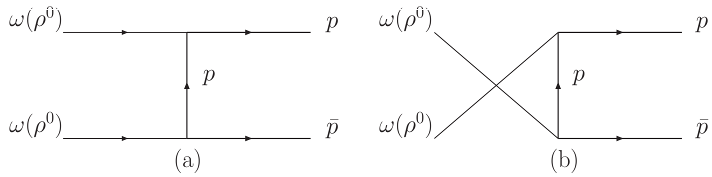

FIG. 3: Diagrams for the process $V\bar{V} \to p\bar{p}$.

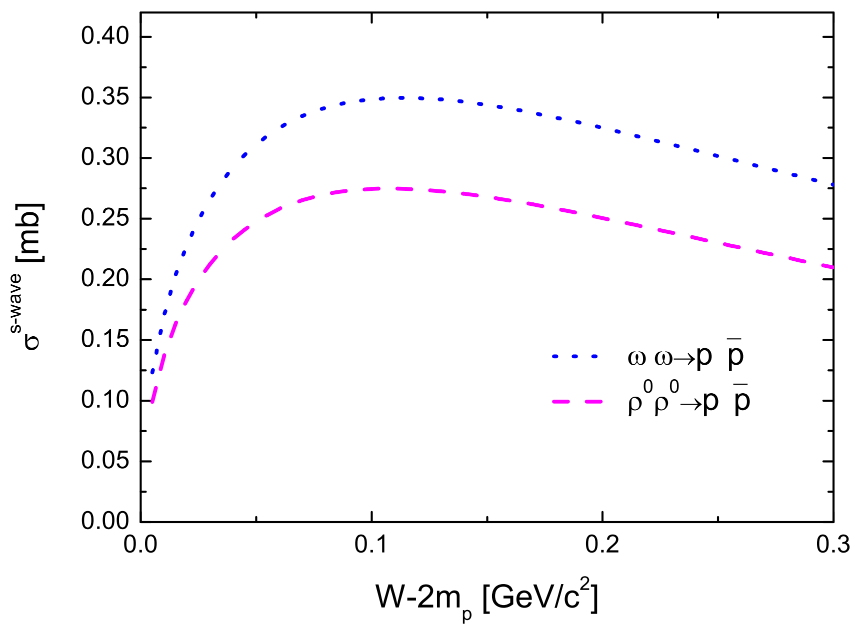

FIG. 4: Energy dependence of cross sections for $V\bar{V} \to p\bar{p}$ with $p\bar{p}$ in the $^1S_0$ state.

which are consistent with the data within both experimental and theoretical uncertainties. This suggests that our $V\bar{V}$ rescattering contributions have not been overestimated. We note that the full calculation without imposing the $^1S_0$ projector gives similar results near threshold which confirms the S-wave dominance.

We can further understand the $V\bar{V}$ rescattering mechanism by looking at the $V\bar{V} \to p\bar{p}$. The reaction can be illustrated by Feynman diagrams in Fig. 3. The $^1S_0$ configuration is also dominant near threshold, i.e. an S-wave decay amplitude. Again, with the same effective Lagrangians, form factors and couplings, we find a quick increase of the cross sections at small values of $(W - 2m_p)$ as shown in Fig. 4. It helps clarify that the intermediate $V\bar{V}$ rescatterings can contribute to the threshold enhancement in the $p\bar{p}$ invariant spectrum in $J/\psi \to \gamma p\bar{p}$.

C. Results for $J/\psi \to \omega p\bar{p}$

Further search for this threshold enhancement was carried out in $J/\psi \to \omega p\bar{p}$ at BES [33], where it was claimed that the $p\bar{p}$ enhancement was absent as shown by the data in Fig. 5. However, Haidenbauer *et al.* [15] suggest that there still exist a similar threshold enhancement due to final state $p\bar{p}$ interaction except that it is much less significant due to kinematic changes and competing hadronic background.

We also extend our formalism to $J/\psi \to \omega p\bar{p}$. The measurement of $J/\psi \to \omega\eta(1405)$ by BES [34] allows us to estimate,

$$\mathrm{BR}(J/\psi \to \omega\eta(1405)) \sim 10^{-3}, \tag{15}$$

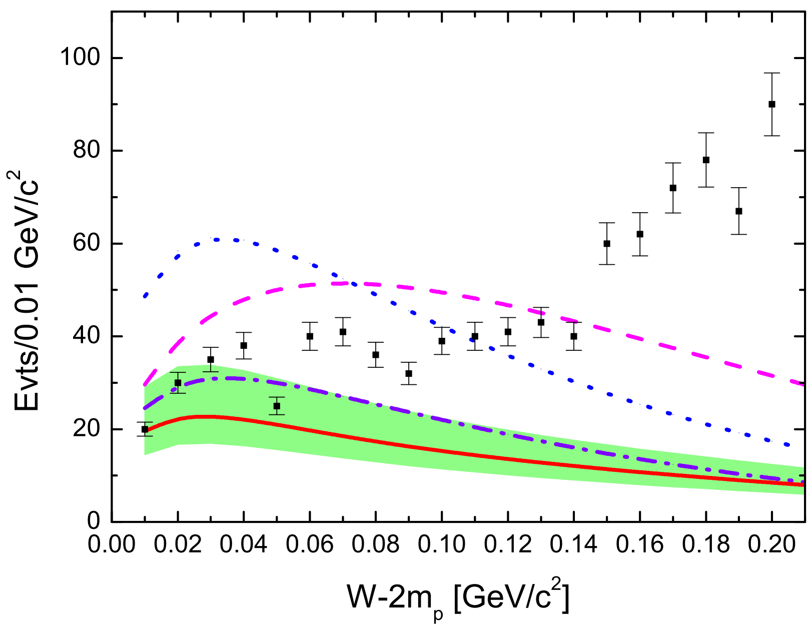

FIG. 5: The $p\bar{p}$ invariant mass spectrum of $J/\psi \to \omega p\bar{p}$. The notation is the same as Fig. 2, and the experimental data are from Ref. [33].

with which the coupling constant is extracted as

$$\frac{g_{\omega\psi\eta}}{m_\psi}\frac{g_{\rho\rho\eta}}{m_\rho} \simeq 0.0093 \text{ GeV}^{-2}. \tag{16}$$

With the other parameters fixed the same as in $J/\psi \to \gamma p\bar{p}$, we plot the $p\bar{p}$ invariant mass distribution for $J/\psi \to \omega p\bar{p}$ in Fig. 5. Again, it shows that the rescattering terms overestimate the cross sections at low $(W - 2m_p)$, while the interference gives much smaller cross section. We do not try to quantitatively describe the data at large invariant masses since they are the kinematics that other partial waves and mechanisms would become important.

It should be noted that our estimate of the $\omega p\bar{p}$ decay is rather rough, and a better measurement of BR$(J/\psi \to \omega\eta(1405))$ and BR$(J/\psi \to \omega\eta(1760))$ will provide a better constraint on our model. However, this does not prevent us from gaining some insights into the $p\bar{p}$ threshold enhancement due to final state interactions. It is essential to recognize that the rescattering transitions via $V\bar{V}$ could be much larger than the direct transitions based on the available experimental evidence [23] and the significant absorptive contributions from the $V\bar{V}$ rescatterings. This can be regarded as a peculiar property of some of those $\eta N\bar{N}$ off-shell couplings. Additional experimental information from $p\bar{p}$ annihilations seems to confirm such a dynamics. Although the determination of the relative phases depends on the requirement of cancellations among the dominant amplitudes, we emphasize that the presence of the threshold enhancement is mainly due to the property of $V\bar{V} \to p\bar{p}$ transitions.

IV. SUMMARY

It is of great importance to recognize that the same mechanism may behave differently in different channels due to kinematic and interferences from other processes. Therefore, it may not appear prominently everywhere. Because of this, it appears to be an attractive solution for our understanding of the $J/\psi \to \gamma p\bar{p}$ and $\omega p\bar{p}$ results. As studied in the literature [9, 10, 11, 12, 13, 14, 15] that $p\bar{p}$ final state interaction can also produce threshold enhancement, it is urged to have a systematic understanding of how these mechanisms exhibit and interfere with each other. We expect that the BES-III experiment in the near future would provide a great opportunity to clarify the underlying dynamics of the $p\bar{p}$ threshold enhancement [35].

Acknowledgement

Authors thanks B.S. Zou, S. Jin and X.-Y. Shen for useful discussions. This work is supported, in part, by the National Natural Science Foundation of China (Grants No. 10675131 and 10491306), Chinese Academy of Sciences (KJCX3-SYW-N2), and the Ministry of Science and Technology of China (2009CB825200).

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